Gunning (T. B.)

THE LARYNX

The Source of the Vowel Sounds;

BY THOMAS BRIAN GUNNING,

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THE SOURCE OF THE VOWEL SOUNDS;

BY THOMAS BRIAN GUNNING,

AUTHOR OF A PAMPHLET ON THE

"TREATMENT OF FRACTURE OF THE LOWER JAW

BY INTERDENTAL SPLINTS;"

AND OF AN EXTENDED MEMOIR ON THE

"MUSCLES OF THE HEAD, NECK, JAW AND

PALATE."

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THE SOURCE OF THE VOWEL SOUNDS.

What I have observed in dental practice, associated with much special attention to speech, as heard in different forms of the mouth, from infancy to old age, not merely in normal conditions, but also in congenital and acquired deficiencies of the palate, and other defects, having convinced me that the source of the vowel sounds is misunderstood by those considered as authority upon the subject, I propose to show:

First, how the vowels are said to be formed in the mouth;

Second, that they cannot be formed in the mouth;

Third, where and how they are formed.

The human larynx divided into upper and lower cavities by the inferior or true vocal chords, and protected by its movable cover, the epiglottis, is well known to be the organ of voice. It is also understood that voice is produced by the air being forced from the lungs through the trachea and vocal chords, and that the pitch of the tones depends upon the vibrations of the vocal chords, as modified by their length, width, tension, etc., while the volume of the tone is regulated by the parts below.

It is also known that each tone of the voice has not only its fundamental tone, but that it includes also what are known as overtones, these being tones whose rates of vibration are twice, three times, four times, five times, etc.—

that of the fundamental, and that different admixtures of the fundamental, and one or more of its overtones form the vowel sounds of speech and song. After much investigation and experiment by men of science, it has been decided that this change of vocal tones into the vowel sounds is made in the cavity of the mouth, say all parts of the vocal tube above the epiglottis. It is supposed that, by appropriate changes in these parts, the resonance of the mouth re-enforces the tone peculiar to the required vowel. The following references to what has been done and said by prominent investigators will make the views now held as to the formation of the vowel sounds more clear. In the year 1799 the Royal Academy of St. Petersburg made the vowel qualities a prize question. Kratzenstein submitted a memoir and also showed how the vowels could be produced by artificial mechanism, and the prize was awarded to him. Von Kempelen, of Vienna, made similar and more elaborate experiments. These scientists stated that the tones of the larynx were changed into vowel sounds by alterations in the size of the oral opening, and the oral canal, that is the aperture between the lips and between the tongue and palate. Mr. John Bishop in his work "On Articulate Sounds and on the Causes and Cure of Impediments of Speech," London 1851, page 17, says: "Vowels have been divided into three classes, having reference to the organs employed in their production, namely, guttural, palatal, and labial," and he endorses these views by explaining how the organs act, and brings in prominently certain vibrations of the lining menbranes of the parts which he considers to be specially active; in the gutturals, the membranes of the fauces, pharynx and soft palate; in the palatals, those of the dorsum of the tongue, and of the hard palate; in the labials, the vibrations in the lips and cheeks. This author also thinks that the change from the sound of *o*, as in bone, to *oo* as in boot, is entirely due to the closer and more projecting position of the lips, and he states distinctly that certain positions of the organs above the epiglottis are indis-

pensable to articulate speech. He thinks that the vowel quality pulsations may be produced by either the air in the mouth, pharynx, and nostrils, or by the *membranes* of these parts; the first, being perhaps, the opinion of Dr. Thomas Young, the last, probably, more according to M. Savart. Mr. Bishop does not state clearly that he inclines to one view more than the other, but evidently thinks the vowel qualities originate in part from both sources.

Professor Tyndall, explaining the nature of the vowel sounds in his fifth Lecture on Sound, at the Royal Institution of Great Britain, published in New York, 1867, says: "We can distinguish one vowel sound from another while assigning to both the same pitch and intensity." * * * "Now, in the vocal organ of man, you have your reed in the vocal chords, and associated with this reed you have the resonant cavity of the mouth, which can so alter its shape as to resound, at will, either to the fundamental tone of the vocal chords or to any of their overtones. Through the agency of the mouth, we can mix together the fundamental tone and the overtones of the voice in different proportions, and the different vowel sounds are due to different admixtures of this kind." Professor Tyndall then selects a tuning fork of a suitable pitch for the required sound, and adjusts his mouth until it resounds to the fork, and then urges air through the larynx, when the particular vowel sound is heard and no other. In this way he decides that it requires the first, second, third, fourth, fifth and seventh tones to form all the different vowel sounds, upon the same fundamental tone of the vocal chords, and the precise tone or tones re-enforced by the mouth for the particular sounds are for U (*oo* in hoop,) 1st or fundamental; O, 2d; A, 3d strong, 2d moderate, 4th and 5th weak; E, 1st weak, 2d comparatively strong, 3d feeble, 4th intense; Ah! 3d feeble, the higher tones especially, 5th and 7th strong. Upon this theory the mouth re-enforces tones ranging in pitch through three octaves less one tone to form the vowel sounds of speech on the same fundamental tone of the vocal chords.

and this range of the mouth's re-enforcement must be increased in proportion to the range in the pitch of the tones of the vocal chords.

Madame Emma Seiler's views upon the formation of the vowel qualities are of great importance, from the fact that she was associated with Prof. Helmholtz in his experiments to ascertain the nature of these sounds. In the translation of her work, "The Voice in Singing," Philadelphia, 1870, she explains the nature of the vowel qualities, as explained by Prof. Helmholtz, and as just now given in the quotations taken from Prof. Tyndall's lecture. Madame Seiler, however, on page 96, says: "But certain vowels, in certain parts of the scale, can be sung far more easily and sweetly than others. The investigation of this fact has taught us that a tone gains in richness when the tone corresponding to the vowel belongs to the overtones of the fundamental tone." This seems to indicate that Madame Seiler considers that the vowel quality is given to the fundamental tones in a fixed range of pitch, and that it does not rise and fall with the pitch of the tones from the vocal chords, as Prof. Tyndall seems to intimate. Mme. Seiler's work shows uncommon acuteness and familiarity with the subject. She says: "The female voice has only a few tones more than an octave upon which every one of the vowels can be distinctly sung;" and on page 114, that "The length of the cavity of the mouth is the greatest in sounding *oo*, the least in *e*, intermediate in *a*." 'In the pure, clear *a*, as in *may*, the cavity is the narrowest.'

It is difficult to discover any practical difference between Prof. Tyndall's and Mme. Seiler's views, and those of Mr. Bishop, upon the action of the organs in forming the vowel sounds of *speech*. They, however, seem to think, that the vowel qualities originate in the general resonance of the mouth, rather than in the vibrations in the membranes of any particular part of it. Many have written upon the vowel sounds of speech, but it is difficult to find in the writings of any one author, all that is necessary to give a com-

prehensive view of what is now believed in regard to them. This arises not so much from any material difference in the views held, as in the special subjects, upon which the writers were engaged. I have, therefore, selected from those whose writings collectively seem to embrace what will give an easy and sufficiently full idea of what is held respecting them. Mr. Bishop writes upon speech and its impediments: Prof. Tyndall, more upon the strictly acoustic bearings of the subject; Mme. Seiler, more upon the voice in singing.

Mr. Bishop describes minutely how the consonants are formed, and the positions taken by the organs of speech in doing this, have an important bearing upon the subject matter of this paper; for the consonants are associated with vowels in the formation of words, and they have also their own special sounds readily distinguished, while the movements and positions necessary to their production are easily demonstrated.

I propose to show briefly some of the movements made in forming the consonants, and the probable effect of these upon the vowel sounds, if these last also originated in the mouth, but first giving a description of the parts used in speech above the epiglottis.

The lower jaw which protects the tongue, larynx and trachea, also gives attachment to muscles which control them in the performance of their functions. Its co-operation in these functions is effected principally by the *temporal* and the *external pterygoid* muscles, the first pulling the upper part ot the ascending ramus backward, and the last drawing it forward. This shuts or opens the teeth and regulates the position of the lower jaw. Thus the *digastric* and other muscles attached to the body of the jaw, and to the hyoid bone, have a base of action, and without this, vocalization and articulation would be impossible. This will be more clearly understood by recollecting that with the teeth closed, the stylo maxillary ligament *slants* down to the angle of the jaw; therefore, while the *temporal* muscle relaxes to allow the *external pterygoid* muscle to draw the condyle

forward under the *eminentia articularis*, the angle is, at the same time, carried back by the ligament, into the perpendicular of its attachment on the styloid process. This allows the jaw to go down bodily, as well as open in front, by which the back teeth of the upper and lower jaws are widely separated, and the size of the oral cavity much enlarged. The nose, with the nostrils through which the air passes to and from the pharynx at the back of the mouth cavity, and the upper and lower lips, with the separation between them, which gives passage to and from the front of the mouth, are well known. The nose can vary the size and position of its anterior openings to a limited extent, but as a whole moves only with the head. The upper lip moves less on its attachment than the lower, this last moving freely with the lower jaw to the full extent to which this bone can carry it. These movements are much less in some persons than in others. The cheeks have also a varied amount of mobility, but yield readily to all the movements of the lower jaw. Each cheek is well controlled by a thin broad muscle, the *buccinator*, which arises from the alveolar process on each jaw, continues forward into both upper and lower lips, and backward on to the pterygo-maxillary ligament, from whence on each side, the *superior constrictor*, a similar muscle, curves back to the centre of the pharynx. These four muscles lie just under the mucous membrane, which covers the inside of the cheeks, and all the parts within the mouth, except the teeth, continues up into the nose, and through the larynx into the lungs. The teeth which stand around within the lips and cheeks, are in the complete temporary set, twenty in number, and should be all in the mouth at three years of age. By six, the jaws have enlarged behind the last infant teeth, for the first permanent molars; by twelve, for the second; and by eighteen, the third permanent molars are generally present. Then the permanent teeth, thirty-two in number, should all be in the mouth, the cavity of which then averages four or five times larger than at the age of three. Its capacity ranges

in the adult from two to four fluid ounces, males having the larger. Through early loss of teeth and other causes, the adult mouth has, in rare cases, less than two ounces capacity. I have never found one which could take in over four ounces of water without swallowing some. The separation between the lips varies much in size compared with the cavity within, and the hard palate, which forms the roof of the mouth, is singularly unlike in size and shape in different persons. The soft palate which extends backward from the hard palate, is complicated in its movements and requires close attention. It can be seen curving downward and showing in its centre the uvula which hangs below its back border. The uvula is the centre of two distinct arches, formed by two pairs of muscles, which are separated below by the tonsils. The posterior arch is smaller than the anterior, and therefore, also well separated from it above. It is formed by the *palato pharyngei* muscles, which by their anterior fibres go down and are inserted into the thyroid cartilage, while the others pass around the sides of the pharynx and some cross each other behind. The anterior arch is formed by the *palato-glossi* muscles, which are inserted into the tongue. The uvula is itself the insertion of a pair of small muscles, which pass back from the centre of the hard palate; while the *levator-palati* muscle comes forward and downward over the edge of the superior constrictor on each side, and spreads out in the upper surface of the soft palate. This pair are the antagonists of those which pass to the uvula from the hard palate. The *tensor palati* of each side controls the tension of the soft palate. The form of the hard palate is such, that the tongue can close up against the edge around the inside of the upper teeth, while the back part of the tongue is so shaped, that it fits the uvula and soft palate exactly, and this closure can be made readily at the same time that the upper and back part of the soft palate also closes the posterior nares.

The tongue at rest lies with its point within the lower front teeth, rising gradually to its centre, where it curves

suddenly down to its connection with the epiglottis, which fits up against it. Just below this the hyoid bone gives support to the tongue, and passes back around on each side, giving attachment by its upper and inner border, to a broad fibro-elastic membrane, which is also attached below around the upper border of the thyroid cartilage. From the back end of the hyoid bone on each side, a round elastic ligament also goes to the superior cornu of the cartilage. These attachments allow considerable movement between the hyoid bone and the thyroid cartilage. The tongue, above and in front of these, has singular mobility. Its point can be put out through the lips, up behind the teeth, against the gum, or drawn back in the mouth; it can also be turned down in front, below the back of the inferior incisors, while the centre goes up close into the roof of the mouth, and the part near the epiglottis is drawn so far forward, that the end of the finger may be placed between them, and this with the epiglottis up, and also pulled forward with the tongue. The tongue also, while fixed in the roof, can be drawn forward at its base so much that the epiglottis going forward with this part, is entirely protected by the tongue above it, as in swallowing. Other positions of the tongue are so easily seen, as not to require explanation here.

It is not surprising, with this wonderful flexibility of the tongue, and the complexity of the parts associated with it in speech, that even such a competent surgeon and so precise an observer as Mr. Bishop, should consider that the vowel sounds were formed in the mouth, and it requires close attention to arrive at a conviction that they are not.

It must be borne in mind that all words, whether in speech or song, without *m* or *n* in combination, are uttered with the soft palate drawn up so as to shut off the nose. This is easily proved by holding the nose shut with thumb and finger, when after sounding any letter of the alphabet other than *m* or *n*, the opening of the soft palate will be heard and felt. It comes down sooner in some sounds than in others. In singing low tones, as seen in the mouth, it ap-

pears to be open, but this is so only in its lower border, and in sounding low tones, with the nose closed, it takes much longer to open than in high tones, in which the velum is drawn up tight, and the tension of the parts then opens it quickly. The velum is drawn up back by the *levators*, which enter the palate above. The small muscles between the spine of the hard palate and uvula, draw the velum down in a curve to fit the tongue, and if the finger is laid upon the tongue so as to press it down where the uvula strikes it in swallowing, or in sounding the guttural consonant *k*, the uvula, if short, will come forward and its back lay upon the finger; while the tongue and velum are in contact to sound *k* or *g* hard, and kept so, the nose can be opened instead of sounding either letter and the sudden current of air will prove that it was firmly closed behind. and this closure is complete even with the larynx prepared to sound the lowest tones of the voice. This isolation of the nose, except in sounds of *m* and *n*, makes it unnecessary to give any special attention to the resonance of its cavity.

Mr. Bishop defines the guttural consonants to be *c* and *g* hard, *k*, *q*, *ch*, *gh*, and says: "The vowel sounds pronounced in *ball*, *bar*, *bat*, *but*, are guttural."

He says *t*, *d*, are lingua-palatal consonants, and the vowels in *bate*, *bet*, *beat*, *bit*, palatal.

He says *b*, *p*, are labial consonants, and the vowel sounds in *bone* and *boot*, labial.

These different sounds are formed upon a tone originated by the vibration of the vocal chords, this tone not being at all altered in pitch, but only so that the vowel quality is given to it, and so far as the consonants as used in speech, are more than the mere beginning or ending of a syllable or word, they consist of some vowel sound, and this, although slight, is readily distinguished, for *t* or *k*, in combination with the same vowel are not confounded, although both are formed out of sight.

Now, if the consonants and vowels, classed as guttural, were sounded only with each other, it would be easier to

believe in Mr. Bishop's theory; but the guttural consonants are used quite as well with the palatal and labial vowels, and the labial and other consonants are also used with all the vowels. In fact, while any consonant is used with any vowel, consonants of the different classes are used with the same vowel, or the same vowel sound, in syllables and words having one continuous vowel sound. For instance, in sounding *cop*, there is no alteration of the vowel sound, but on Mr. Bishop's theory, *cop* could not be sounded at all, for in passing to form the labial *p*, it would end as *coop*; the word *cob*, would be *co-oob* as the lower lip closed to form b.

I have thus far confined myself to *o* and *oo*, as Mr. B. says the transition from one to the other is entirely due to the change in the state of the lips. Now, if it be said, that state of the lips may be more than position, that it may also include vibration—take the word *cove*. Here the lip in closing up to form the *v*, also vibrates, but although it goes up past the position for *oo* and then rests in it, the word gives no sound of *oo* whatever. It is clear therefore, that something more than position, or *state* of the lips, is needed to make the difference between *o* and *oo*.

These examples could be multiplied, but without advantage. We know how and where the consonants are formed, and in the transitions from one to the other, it is impossible that a pure vowel sound could continue unchanged, were they formed in close proximity, indeed in the mouth at all. Mr. Bishop himself says: "Diphthongs are not merely sounds resulting from the combination of two simple vowels following each other in rapid succession, but are also in part the effect of the movements of the articulating organs on the vowel sounds, during the transition of these organs from the position of the first vowel to that of the second." Now if the vowel sounds originated in the mouth, during transition of the organs to form different *consonants*, the continued vowel sound between them would be altered. With these movements it is impossible that vibration of the parts designated can add the vowel quality to the fundamental

tone of the voice, and also hold the vowel sound steady and pure. Further, the vowel sound may be formed well, although the fingers are against the teeth in place of the lips, and also in cases of congenital cleft palate, where not only the soft but the hard palate, and even the upper lip is deficient. Of course in these cases the sound is more or less nasal. But this is remedied by a plate of hard rubber, which covers the whole of the roof of the mouth, passes up above the remnants of the soft palate, fills up all across, and ends in the pharynx opposite the tubercle of the atlas. By this, vibrations of the hard and soft palate and nearly the whole of the pharynx are cut off, but the vowel sounds are perfect, and the consonants so far, that the imperfect condition of the palate is not suspected; and there can be no vibration whatever in the hard rubber. The vowels are perfect when all the gum of both jaws, and the roof of the mouth are covered with plates holding artificial teeth, the plates being of hard rubber, metal, or porcelain, and vibrations in, or beneath them impossible. Nor is the vibration, nor in fact the presence of the tongue indispensable; for the records are indisputable which show that the loss of the tongue is not followed by loss of speech, and that the *vowel* sounds are articulated perfectly with the tongue cut off nearly against the epiglottis.

It is necessary to consider carefully, at this point, what this change of tone to vowel sound is in acoustic quality, or value. This is not definitely settled. Mr. Willis,* quoted largely by Mr. Bishop, and referred to by Prof. Tyndall, makes the difference in pitch between the vowel quality in *ee*, as in *see*, and *o*, as in *no*, to be three octaves and a fifth (g'''' to c'') marking that in the lowest vowel sound *oo*, as in *boot*, indefinite. This would make a difference of, say, four octaves between the highest and lowest vowel quality. He used a reed which sounded the same fundamental, and the pipe which surmounted the reed and resounded to it, had

* Cambridge Philosophical Transactions, Vol. iii. 1829.

always the same outlet, but was varied in length to make it yield the vowels, the length for *ee* being .38 of an inch, and for *o*, 4.7 inches,— over twelve times longer. This difference in the depth of the resonant cavity would be increased to sixteen times for *oo*, the lowest vowel quality, if this vowel sound were just four octaves below *ee*,—the intermediate vowels being obtained between these extremes.

Prof. Helmholtz gives a scale of four octaves less a tone and a half, in which the overtones of the vowels as pronounced in the north of Germany are particularly strong.

Dr. C. L. Merkel, of Leipzig, gives a range of three octaves, less two and a half tones, to the pitches of the vowels, according to his own habits of speech.

Prof. Tyndall says it requires three octaves less one tone to form the vowel sounds upon the same fundamental, and this range must be increased as far as the tones of the vocal chords range. Now the range of the voice in speaking and singing, being, say, two octaves, full two-thirds of this range of the fundamental tones, and their overtones should be so re-enforced by the mouth as to form perfect vowel sounds. To do this, every mouth must alter so as to augment tones ranging through four octaves and a third; and as the male voice is an octave lower than the female, the range of tones necessary to be re-enforced by the mouth in both sexes is over five octaves. For the purpose of this paper, however, it is not important that the scale of the vowel qualities should be precisely known.

In the mechanism used by Mr. Willis, to find the acoustic values of the vowel qualities, the pipe was necessarily greatly varied in length. This presents, at once, an insurmountable objection to the theory that the vowel qualities of speech originate in the cavity of the mouth, which has little capability of altering its length. In other respects, however, the acoustic possibilities of the mouth, are not so easily settled, or the matter would have been decided long ago.

In Willis' experiment we see that the resonant cavity of the pipe is longer, compared with its outlet, in propor-

tion to the gravity of the tone, and shorter as the tone becomes acute. It may, therefore, be thought that the equivalent of this change in the resonant cavity, would be found by varying the size of the outlet, the cavity remaining the same. My own experiments show, however, that in a glass bottle having a mouth about one inch in diameter, partly filled with water, leaving a space of four and a quarter fluid ounces capacity, the cavity resounded to *c''*; with the mouth half closed, *b'* flat; while *g'*, only two tones and a half below *c''*, would not resound at any closure.

To show the effect of lessening the resonant cavity, while retaining the same opening, 3½ ounces of space gave *e''*; 2½, *g''*; 1⅝, *c'''*. This 3½ ounces of space is about the capacity of a large adult mouth, yet this space reduced more than one half, by pouring in water, resounded to a pitch only four tones, or two-thirds of an octave higher. This arose from the water not filling up half the length of air space, as the bottle was wider below than at its neck. In a straight tube to fill half the space, would halve the length, and the empty part would resound to an octave higher.

Four straight jars without necks, their capacities being respectively 1½, 2¾, 4½, and 9 fluid ounces, covered with the same sheet of gutta-percha, with an opening in the centre about the shape and size of a small mouth, the opening, that is, between the lips responded to *c'''*, *g''*, *e''*, *b'* flat. This is a difference of only one whole tone more than an octave, between the largest and smallest jars, and yet the large jar was three inches deep—just twice the depth of the small one, and six times its capacity. The three smallest jars differ in size far more than any cavity of the mouth, from any possible alteration made by the tongue in speech; yet their whole range of pitch was but four tones, and even this was caused by the difference in their depth of air cavity, which was far greater in any two of them than is possible to the cavity of any one mouth in speech.

Length, or depth, has more influence on pitch, than mere size of cavity, yet a proportionate size is also necessary; for

a wide mouthed bottle filled with water to three inches from the top, and resounding to c'', on being laid down so far that the water came just to the edge of the mouth, by which the space was doubled in length, but still the same in size, resounded to only one tone lower, not the octave lower, as it would had the space been doubled in size, as well as in length, instead of tapering. Again a straight tube, with space four inches deep, and of $2\frac{3}{4}$ fluid ounces capacity, resounded to e''; and on laying it down as above, to c'', two tones lower. These resonant cavities were respectively three and four inches deep, while the mouths of adults, between the back of the pharynx, and the closing ridge of the lips, generally range from three and a quarter, to three and three-quarter inches, rarely being as short as three or as long as four.

By these tests of mere resonance made, like Prof. Tyndall's, at the outlet of the cavity it is seen that *altering the size of the outlet* affords but a very limited range in the pitch of the tone; further that a cavity of a certain size, *doubled in length, but without increased capacity*, varies only a little in its tone or key note, and finally that changing the size of the resonant cavity without proportionate *increase of length in one direction*, has also but little effect on pitch. The mouth has only the most limited power to lengthen its cavity, and this is confined to the lips, for the constrictor muscles which give form to the sides and back of the pharynx, are firmly held in the centre behind. These experiments show therefore that the human mouth cannot form the vowel qualities, by altering its outlet between the lips, its shape, or its capacity.

The remarks previously made as to the effect of cleft palate, and imperfect lips, loss of the tongue, and other acquired injuries, are equally pertinent here; for any one of them would prevent the resonance of the mouth from forming the vowel qualities; and as the vowels are comparatively perfect in such cases, it is clear that they originate elsewhere. In fact, if they did not, speech would be impossible, for the changes in the organs to form even the

consonants, would prevent a continuous and pure vowel sound in any syllable into which they entered, if the resonance of the mouth had any considerable influence.

Further, the changes in position of the organs, as seen in singing, show plainly that they act in subordination to the general pitch of the voice as a whole, and not for the addition of the vowel qualities. In high tones the mouth opens wide; in low tones the lips are comparatively close; while the soft palate is high and tense in acute tones, but low and loose in grave tones; and these great changes, so plainly seen, are made to enable the mouth to transmit the tones of the larynx, which with all its special parts for forming the voice, and varying its pitch, gives less than two octaves range to the average of voices, as used in singing, or far less than the range of pitch necessary in the vowel qualities, to form the vowel sounds of any one person.

It is thus clearly seen that the mouth is supplied with the vowel sounds already formed upon the tones of the larynx. I purpose to show now, that the addition of the vowel qualities to the tones of the vocal chords is made in the upper cavity of the larynx. This cavity is bounded below by the true vocal chords, which pass back in the thyroid cartilage from their attachment on each side of the centre, corresponding to the vertical ridge so prominent and easily seen in the male larynx in front of the throat. The vocal chords are attached in the inside, a little above the small membrane felt as a notch in the front of the neck, at the inferior border of the thyroid cartilage. The false vocal chords are close above; and, higher still, at the inside of the extreme point known as the *pomum Adami*, the ligament of the epiglottis is attached. From this point, the upper edge of each side of the cartilage may be felt, curving upward and backward, and if the finger is laid on the membrane between, the body of the hyoid bone will be felt above, as a hard round projection in the soft parts within the lower jaw. The support given by this bone to the larynx by means of this membrane, which passes down around

to the upper border of the thyroid cartilage, has been before spoken of. The epiglottis passes up from its ligamentous attachment to the thyroid cartilage, and is attached by an elastic ligament to the inside or posterior surface of the body of the hyoid bone, after which it emerges at the back of the tongue, as a broad elastic cover to the superior aperture of the larynx. The tongue, as before stated, commences at, and rests upon the top of the hyoid bone. This bone, however, is not the only connection between the tongue and epiglottis, as three folds of mucous membrane also link them together in the mouth. The point of the thyroid cartilage in front of the throat, known as the *pomum Adami*, is some distance below the hyoid bone, but in swallowing it may be felt to rise up close to the bone, and then go forward with it toward the inside of the chin. This is the highest position which the cartilage can reach, and, by following it with the finger, we feel that the upper cavity of the larynx is subjected to great changes in shape and capacity. During the act of swallowing it may be noticed also, that the tongue is fixed in the roof of the mouth, and the hyoid bone, therefore, in going forward, draws the larynx, epiglottis and base of the tongue under the part above. By this, the epiglottis, which is usually upright, is carried down backward over the superior aperture of the larynx, which is thus closed, and well protected while food passes down behind. With the finger upon the thyroid cartilage, it may be felt that its sides widen rapidly from the *pomum Adami* in front, and, as the vertical ridge in front recedes down to the lower border, and the upper borders of the thyroid cartilage, with the membrane between, (which, with the attachment of the epiglottis extend up to the hyoid bone,) also recede, it follows that the inner surfaces of the front of the upper cavity of the larynx, converge to the inside of the point of the *pomum Adami*. The upper surface, however, along the course of the epiglottis, and the aperture, as well, which the latter modifies, vary considerably in deglutition, vocalization and articulation. In movements of the tongue outside of these

functions, the hyoid bone, although supporting the tongue, changes but little in relative position to the thyroid cartilage, and in mere movements of the jaw to open the mouth, the hyoid bone, and the thyroid cartilage are virtually motionless. Consideration of these statements of the movements in deglutition will assist in discriminating between them, and those of vocalization and articulation yet to be considered. If the arm is laid upon the breast, with the forefinger resting on the membrane between the superior borders of the thyroid cartilage, and its end against the hyoid bone, while the second finger and thumb lay hold of the cartilage below the *pomum Adami*, any movement in these parts will be distinctly felt. The hand may be steadied equally by resting the knuckle of the forefinger against the chin above. Allowance must be made in the latter position for movements of the jaw in opening the mouth, and in the former for movements of the breast in breathing.

The opinion is generally entertained that the larynx rises and falls with the pitch of the tone; that is, that it rises in singing from the lowest tone of the voice, *through the whole scale*, up to the highest, and falls with the tones in descending the scale. This error has no doubt arisen from the fact that, in a few of the lowest notes, the larynx falls, and in a few of the highest it rises; and the custom of using certain consonants in connection with different vowel sounds in vocal exercises has, by complicating the action of the parts, made the discovery of the truth a matter of extreme difficulty. But by singing up and down, through the scale of the voice, and using only *one* vowel sound, *without a consonant*, it will be found that there is an octave or more in the scale, in which the larynx neither falls nor rises, and that its movements down and up are all below and above that part of the scale; and this part of the scale is that in which we usually speak; and it will differ in pitch according to the voice.

Now, with the fingers and thumb upon the larynx, while sounding the *different* vowels upon any one tone within the

speaking scale, whether in speaking or singing voice, it will be found that the relative positions of the hyoid bone and larynx change with *every* alteration of the vowel sound. In using the vowel sounds, a, e, i, o, u, pronounced *ah*, *a*, *ee*, *o*, *oo*, the larynx rises but little in *ah*; more in *a*, in which the hyoid bone also moves toward the chin; but in *ee* the thyroid cartilage is drawn up very close to the hyoid bone, which last is also drawn *much* nearer to the chin than in *a*; in sounding *o*, the larynx does not rise at all, but the membrane between it and the hyoid bone tightens, the bone descends some, and goes forward; in *oo*, the larynx rises much, the membrane is very tight, and the bone drawn forcibly forward. The English vowels can be formed only by different positions of the hyoid bone and larynx relatively to each other, and this is true of every possible modification of vowel sounds, and even in the whispering voice. By sounding any one consonant with the different vowels, and making allowance for the movement of the hyoid bone in carrying the tongue up, as in *k*, or *t*, it may be felt that the same relative changes are made for each particular vowel sound as without any consonant. In fact, this is so in all cases, whether initial or terminal consonants are used, and under any circumstances in which vocal tone is heard, for no tone is uttered except with some modification of vowel quality. Not only the nasals, and others, termed semi-vowels, but even the consonants except in their beginning or ending, and when initial or terminal (in which cases the contact of the parts above the epiglottis gives them distinctive characters,) except also, perhaps, in their sibilation and buzzing, are, as shown by the movemements in the hyoid bone, thyroid cartilage, and the membrane between them, vowel sounds, derived from the larynx.

In analyzing these movements, a striking resemblance in them is discovered in forming the highest and lowest vowel sounds. These are *i*, (sounded as ee in eel,) and *u*, (oo as in boot.) The difference is, that in the first, the hyoid bone and the thyroid cartilage are a little closer together, and the

membrane perhaps rather tighter than in the other, while the hyoid bone is a little lower in *u*. In both, the hyoid bone is forcibly drawn toward the chin, with no perceptible difference, unless it be more forward in *u*. These vowels therefore afford the best opportunity for judging how the cavity of the mouth, and the organs within it, affect the tones of the vocal chords, and the sounds which pass the epiglottis; for the special qualities of these vowels are certainly the two extremes in pitch, not only according to Helmholtz, Merkel, Donders, and others, but as proved by Mr. Willis, whose opinions are entitled to the highest consideration. I shall therefore, in explaining the movements within the mouth and their effects, use the vowels according to the pitch of their special acoustic qualities. This will place them in the following order: *i*, *e*, *a*, *o*, *u*.

The lips, so prominently seen in speech, and which, like all the parts *within* the mouth, contribute to its perfect utterance, do not give any portion of the vowel quality to any vowel, except so far as they may be considered to do so by appropriately changing to give the vocal sound *as a whole*, a suitable outlet. In speaking the lower lip is specially active in movements appropriate to the labial consonants; but good vowels may be uttered while the lips are held wide apart, and in singing perfect vowels are heard while the lips are held far apart to give a proper quality, and outlet to the higher tones. Neither the cheeks, by their lining membrane and muscles; nor the muscles and the membrane which extend back to the centre of the pharynx, and control the size of the oral cavity, so far as proper tension can effect it, (although both, therefore, exert important influence upon each tone as a whole,) nor the tonsils which vary so much in size, contribute anything to the vowel qualities. The soft palate is important to the vowel sounds only in closing the entrance to the nose with suitable tension. The hard palate, and the gum and teeth of both jaws are important for their influence on, and their transmission of the voice as a whole; but all these are so different in different persons, and in the

same individual at different times, that if the vowel sounds depended upon them for their special characters, speech could rarely be perfect, and would be at best so insecure, and so often lost, as to be of no general use. The vowel sounds may be perfectly and easily formed, even when the *rugæ* on the upper gum, extending up toward the roof of the mouth, are covered with a hard plate which presents a smooth polished surface to the tongue. The flexibility of the tongue, and its activity in speech, are so great that it is extremely difficult to define strictly what it does, and what it does not do, in articulation. It has been already shown that, after its loss, the vowels are perfectly enunciated, but the fact remains that the tongue when present, and in good condition, moves actively in the changes from one vowel sound to another, not only in speaking and whispering, but also in singing. In speaking and whispering the vowel *i* (ee.) the point of the tongue is down against the gum and inside of the lower front teeth, its centre rounding nearly up to the front of the hard palate. Now, if the finger is pushed up over the tongue, and curved suddenly down, it will be found that the tongue is pulled forward extremely at the centre of its base, but curving back on each side, while the epiglottis which is also drawn forward, leaving the aperture of the larynx wide open, is so far from the tongue that the end of the finger can go down between them. In *e* (a,) the tongue is lower in its centre, leaving a larger opening above, its base with the epiglottis being further back than in *i*, while they are also closer together. In *a* (ah,) the tongue is higher behind, its base further back, and close against the epiglottis, and both, also, nearer the back of the pharynx.

In *o*, the tongue is still higher behind, while its base with the epiglottis is so far back that the finger in examination presses the pharynx so much that it is difficult to bear. In *u* (oo,) these positions of the tongue up back, and down against the epiglottis, are so extreme that prolonged examination with the finger is unendurable. In *singing* the two

higher vowels *i* and *e*, the tongue is not so close to the front of the hard palate, as in *speaking* them; in singing the three lower vowels, the tongue is about as near to the back of the palate as in speaking and whispering. The tongue does not seem to alter its position, in singing, between high and low tones, except *in the notes above and below the speaking scale of the voice*

In these movements to form the vowels, the parts above the epiglottis are so arranged that brief explanation will clearly show that they do not act for the addition of the vowel qualities to the tones of the vocal chords, to any considerable extent, except in assisting to have this addition made below the epiglottis, or at the aperture of the larynx which it modifies. In sounding *i* (ee,) the cavity of the mouth is larger, compared with the outlet between the tongue and the front of the hard palate, than in the other vowels, whose overtones are lower. This, as shown previously, is contrary to the acoustic law which governs resonance, which is, that to exalt or strengthen acute tones, the resonant cavity must be smaller in proportion to its outlet, than in grave tones. The same inconsistency exists as to the other vowels, for the examination of the parts within the mouth, which I have before made, proves that the positions taken by the tongue, within the cavity of the mouth, during the utterance of the other vowels, make the outlet between the palate just behind the upper front teeth and the tongue below it, larger, and the cavity within, smaller, as the overtones which characterize the vowels lower in pitch. This shows that the cavity of the mouth, with the tongue and other parts within, do not act to add the vowel qualities to the tones of the vocal chords, during their passage through the mouth. The movements of the tongue, however, in assisting and complementing the epiglottis, show that it acts, in strict accordance with acoustic law, in concert with the epiglottis, to form the vowel qualities before their entrance into the cavity of the mouth, for, in the vowel *i* (ee,) the epiglottis is drawn so far forward

that the resounding portion of the upper cavity of the larynx is shortened, and the aperture very widely opened, and, as the vowels, which are qualified by the re-enforcement of the graver overtones of the vocal chords, are sounded the epiglottis, by going back, and shutting down, not only increases the length of the upper cavity of the larynx, but also lessens the size of its outlet. In these movements it acts in concert with the hyoid bone and thyroid cartilage, previously explained, and it was seen that they are drawn forcibly forward in *i* (ee,) and in *u* (oo,) and these vowels include the two extremes of the vowel qualities.

By this co operation a short resonant cavity, with a large and clear outlet, is gained to re-enforce the high overtones of *i* (ee,) and a long cavity with small outlet is produced, opening nearly against the back of the pharynx to do the same for the low tone of *u* (oo.)

Prof. Tyndall's experiments with a tuning fork, held at the entrance of his mouth, are not only unreliable, but necessarily incorrect. The difficulty most apparent when the tuning fork is used, is to adjust the tongue, lips, &c., so that the cavity of the mouth will resound without their taking the true adjustment from life long habit. The vowel corresponding to the fork being known, this disposition of the vocal organs to assume the positions necessary for its production in speech becomes, in this experiment, almost if not quite unavoidable. He says that after adjusting the cavity of his mouth so that it resounds forcibly to the fork, he obtains the vowel sound without altering in the least the shape or size of his mouth. But it is a mistake to suppose that only the cavity of his mouth resounded, for the upper cavity of the larynx was in communication with it, and any resonance obtained included that of all the space down to the vocal chords. I adopted Prof. Tyndall's own method of holding the fork at the outside or entrance to the resonant cavity, but used bottles, jars, and tubes in the experiments detailed above, to show that the vowel qualities are not formed in the mouth. But these fixed cavities, reliable as

they are and useful for this purpose, do not, however, meet all the acoustic points involved in speech; nor is this done even in Mr. Willis' experiments with the reed and adjustable pipe, although they are so free from any liability to error, that his results are demonstrations. But these experiments do involve principles having important bearings upon the whole matter.

The human voice, formed by the vibrations of the vocal chords is, from its commencement in the larynx to its exit at the lips, subject to modification in and from the vocal tube. Although, as shown, the vowel sounds do not originate in the mouth, this cavity and the organs within and around it do effect them, and it is because of this influence and modification no doubt, that Mr. Bishop, Prof. Tyndall, and all who have treated of speech, have been misled as to their source. I purpose to show very briefly now how these parts exert their influence, and conform in their action to the demonstration already made that the *larynx* is the source of the vowel sounds. This will be done without leading the reader deeply into a consideration of cataphonics, the examination of the acoustic features of speech not being the object of this paper.

Examination of the movements of the tongue in sounding the vowels in the order or pitch of their special qualities shows that in the vowel *a* (ah.) the tongue, like the thyroid cartilage, remains virtually still; that as the vowel qualities ascend in pitch, the tongue rises toward the front, and leaves a larger cavity behind; and that, on the contrary, as the vowel qualities descend in pitch, the tongue rises higher behind and enlarges the cavity in front. By these movements little change is made in the size of the mouth cavity: the great alteration is, that in the vowels having the higher quality the resonant cavity of the mouth is shut in behind the tongue, while in those having the lower quality, the tongue rises behind, and the resonant cavity is in front. The base of the tongue is seen to be close against the epiglottis in *a* (ah.) This thin fibro-cartilaginous cover to the

aperture of the larynx is thus steadied, and this assistance of the tongue is also given to the epiglottis in all the sounds whose vowel qualities are of lower pitch. In those vowels, on the other hand, whose overtones are higher than in *a* (ah,) the tongue leaves the epiglottis free. By this the elasticity of the epiglottis, and its smooth inclined surfaces assist in forming the higher vowel qualities. In sounding *i* (ee,) it has been shown that the tongue while thus drawn forward at its base, also rises so abruptly that its centre is near the roof of the mouth, leaving only a very small outlet; and, as the *point* of the tongue is at the same time down behind the lower front teeth, its rounded surface is close to the projecting and mobile *rugæ*, so prominent in the palate where it curves up backward from inside the upper front teeth. By this the reflections from the uneven and mobile surfaces, restore the quality of the laryngeal sound, which would otherwise remain so effected by the large resonant cavity of the mouth, that it would not yield the pure sound of *ee* at the lips without extreme action of the parts entering into the formation of the upper cavity of the larynx. The lips are of less importance for *ee* than any other vowel. In hissing or sibilation, as heard in sounding *s*, the larynx merely rises with the hyoid bone to allow the tongue to reach the palate. It is seen that in the vowels whose qualities are low in pitch the tongue rises behind, and leaves the resonant cavity open in front. Thus in using the vowel *u* (oo,) in speech, especially in low tones, the lips are important to assist and give a proper outlet to the sound. When the lips are imperfect more change is necessary in the positions of the parts forming the upper cavity of the larynx. The change is easily detected by holding the fingers upon the front of the thyroid cartilage and sounding this vowel, first as it is usually spoken, and then with the lips widely opened.

The lips usually make a somewhat rounder outlet for *o*, and *oo*, than for *ee*. It is also probable that the back of the tongue and the pharynx which it lies so high against in

o and *oo*, conform their outlet for these vowels to that at the lips. In whispering the same changes are made by the organs above the inferior vocal chords, as in speaking, but the expulsive power of the chest is weaker. In singing, however, the lips are frequently quite wide apart, and in singing *i* (ee,) in addition to this, the tongue is never so near the roof of the mouth as in speaking, and yet within the medium scale of the voice the vowel sounds are well formed.

By these and former observations throughout this paper, it appears that the upper cavity of the larynx not only forms the vowel sounds in the first instance, but also continues to keep them perfect in the many different conditions and positions of the lips, tongue, and other parts above the epiglottis. This is confirmed by using any vowel sound in connection with and followed by the nasals *m* or *n*. It will then be found that the vowel sound is enunciated perfectly, although associated with the buzzing consequent upon the vibration of the nostrils, and also affected by the peculiar resonance of the cavity itself. When the nasal *m* or *n* precedes the vowel, the soft palate frequently shuts off the nose at the commencement of the vowel sound, which is then heard through the lips only, and therefore free from any influence of the nasal cavity or the nostrils.

In the vowel sounds which pass through the nose the influence of the lips, tongue and cavity of the mouth is very limited, but since the larynx is active the sounds are easily distinguished.

It has been recently shown by Mme. Seiler that the female voice has only a few tones more than an octave in which all the vowels can be distinctly sung, and it has been long known that the vowel *u* (oo in boot,) cannot be sounded by some soprano singers on the highest notes of the voice, even where *i* (ee,) is possible. There is, therefore, a more limited range to the vowel sounds than to the tone of the voice. This is owing, no doubt, to the fact that in the highest notes the hyoid bone is drawn so *forcibly* forward, and

the membrane attached to it is made so tense, that no change can be made in its relation to the thyroid cartilage. The relative position of the hyoid bone is more forward for *oo* than *ee*, while the epiglottis is farther back in *oo*, and perhaps too near the back of the pharynx for the sound to escape. The limit of the power to form the vowel sounds appears to be reached only with that of the ability to change the form of the upper cavity of the larynx.

Up to this point the only reference made to the false vocal chords was the statement, after telling that the true chords, the originators of voice, were attached to the inside of the thyroid cartilage a little above the membrane felt as a notch in front of the neck, that "the false vocal chords are close above." The position and relation of these two pairs of vocal chords are very peculiar. The true or inferior chord passes back from the thyroid cartilage to the extreme end of the projecting point of the *arytenoid cartilage*, while the false or superior chord is attached above, on the receding front of the *arytenoid cartilage*. Between these chords, on each side of the larynx, the narrow slit, known as the ventricle, gives entrance at its anterior part to the membranous sac, situated between the superior vocal chord and the inner surface of the thyroid cartilage, and extending up frequently to its superior border. The investigation into the physiological action of the larynx in voice, aided by the laryngoscope, first used for this purpose by Garcia in 1855, and by others since then,—especially by Mme. Seiler when assisting Prof. Helmholtz in his investigation of the vowel tones and the registers of the female voice, as shown in her book, Philadelphia, 1870—have resulted in the opinion that the superior vocal chords exert little influence upon voice or speech. Researches, however, which left the movements of the upper cavity of the larynx in articulation undiscovered, would naturally fail to discover anything relating to the vowel sounds in the movements of the upper borders of the ventricles.

In view, however, of the fact that alteration of the inferior vocal chords cannot be made without affecting the chords close above, and of the peculiar activity in the upper cavity of the larynx during vowel sounds, together with the further fact that, in singing, the cavity of the mouth, and the surrounding organs are engaged in giving expression more to the vocal tones, than to the vowel sounds, I infer that the upper vocal chords, the ventricles, and their associated sacs, assist in forming the vowel qualities, at least, when the other parts of the apparatus of speech are specially active in vocal expression. It is also probable that, even in speech, the vowels having the higher qualities are in part formed by them. My own observations and experiments with the natural organs, and by other means, indicate that they are. But this subject may shortly be better understood; for a laryngoscope might be arranged with a double tube to fit into the roof of the mouth, over the tongue, so that the superior vocal chords in the vowel sound *ee* could be observed through one tube, proper light being thrown in through the other.

It is probable that in very few cases has the *whole* of the tongue been lost. If any is left in front of the epiglottis, it is to be expected that it would be more on the sides where the tongue goes further back, and where the muscles, which pass down from the styloid processes, enter it, and these muscles would therefore still remain to draw any portion of the tongue back. That some part does remain in front of the epiglottis in every case in which speech is left at all perfect seems probable. In cases where it has been taken away for punishment it is hardly possible that, unskillful as the executioners must be, they could get at the tongue very low down. In the case of Robert Rawlings the whole tongue was, it is said, removed because of cancer, by Mr. Nunneley in 1861, and the patient spoke well shortly after the operation. The Hon. Edward Twistleton reports and remarks upon this case very fully in his work, "The Tongue not Essential to Speech," London, 1873. At his request Raw-

lings submitted his mouth to Sir Charles Lyell, Dr. Milman, Professors Huxley, Owen and Faraday. The letters *t* and *d* could not be pronounced as, to form them, the tongue goes up to the gum just inside the upper front teeth, but the speech was on the whole good. It does not appear in this case that the epiglottis was seen by any of the gentlemen who examined the mouth. This silence in regard to so important a point indicates that some of the tongue yet covered the epiglottis. Judging from Sir Charles Lyell's statement, enough of the tongue remained to give attachment to the muscles which draw the tongue back, and probably sufficient to pad the epiglottis, and hold it steady under the vibration of the low tones. Certainly there was none that could in the least affect the resonance of the mouth. If, in any case, the epiglottis were left entirely exposed, it is not likely that the speech would be as perfect as in Rawling's case. The movements made by the base of the tongue in the vowel sounds are merely like those of the epiglottis, which it complements. In addition to this its body and point aid in forming the consonants, except those formed by the lips, or by the lower lip and the upper teeth. Its movements in the mouth are regulated so as not to interfere with its relations to the epiglottis or alter the vowel quality, and in some sounds perhaps, it even assists in keeping them perfect in disadvantageous conditions of the mouth cavity. It is not surprising, therefore, that it should long be supposed that speech was more dependent upon the tongue than it really is; but notwithstanding the very great importance attached to it in regard to its participation in speech, the fact that the tongue is the *superior epiglottis* has never before been shown, nor, so far as I know, ever suspected. With this in view, it is seen how the epiglottis itself can be injured or lost, and a fair capability of speech remain. Intelligible speech is also possible after loss of the tongue, if the epiglottis is intact, so that the usefulness of the larynx is doubly secured.

The larynx is also protected by the projecting lower jaw. This bone, moved by muscles attached to its upper termination (in a line with the opening of the ear,) gives a base of support by its lower part) to the muscles of the hyoid bone and tongue, enabling them to act efficiently in vocalization and articulation. This control of the lower jaw at its upper extremities in man, so different from that of the lower animals, is associated with a marked peculiarity in the human hyoid bone. The ends of the hyoid bone in the dog, the sheep, the deer and other animals articulate "close," that is, directly with the upper cornua of the thyroid cartilage, and no play consequently is possible; in man on the other hand, great mobility is secured in these parts by means of an intervening flexible ligament, between the greater cornu of the hyoid bone, and the superior cornu of the thyroid cartilage, by which, change in their relative positions can be made at will.

Through these peculiarities of the jaw and hyoid bone the human larynx can be controlled and supplemented, and the wonderful faculty of speech is made possible.